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CULTURE AND SOCIETY

Leonardo da Vinci: The Archetype of Sleeping Beauty in Science

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Abstract

The article examines the body of literature on Leonardo da Vinci using bibliometric methods. The questions of whether Leonardo can be called a "sleeping beauty" in science and what "awakened" him for public attention are addressed. We argue that the first paper that "awakened" a large body of citations for Leonardo's work is in physics (optics), published more than 300 years after his death, and until today physics remains the most cited field of Leonardo's interests in science (based on Scopus database), even though da Vinci left an enormous heritage in different fields due to his versatile interests and insatiate curiosity. However, the Google Scholar search engine shows a different result. Whereas the academic world finds more interest in Leonardo as a physician, popular interest focuses on Leonardo as an artist. The holistic approach that da Vinci adhered to in studying the world makes any attempt to define him in specific terms doomed to failure.

Keywords Premature discovery · Delayed recognition · Sleeping beauty · Leonardo da Vinci · Bibliometrics

The course of scientific research has contradictory directions these days. Even though interdisciplinarity in research is enhanced, the interdisciplinary journals receive fewer citations than the mainstream journals, and the interdisciplinary studies are funded less than the disciplinary research (Bromham et al. 2016). These opposing trends reflect the traditional tension between mono-disciplinary science and interdisciplinary research that according to Kuhn is the tension that exists between tradition and innovation (Kuhn 1959).

Science develops by combining both approaches, the well-established theories and the innovative ones, which are produced by collaborating researchers belonging to different disciplines. Each is contributing his expertise to the scientific process, and in this kind of cooperative work knowledge becomes the possession of a group (Andersen 2013).

Contemporary science is built of the both approaches, but in the fifteenth century there was little division among fields of science. The formation of universities started already in the twelfth century in Europe, and at the end of the Middle Ages there were already around 80 universities across this continent (Haskins 1957, p. 20). Haskins mentions that the apparent sameness and uniform impressions of the Middle Ages were false, since at that time there already was diversity of schools of thought.

Nevertheless, there were only four known study disciplines at that time: art, canon law, medicine, and theology. In the time of the Renaissance, the number of disciplines in the universities increased, and the boundaries among them became more definite: in the following centuries and especially since the seventeenth century new disciplines appeared, and since the mid-1800s the disciplines started to fragment; this process continues these days and has gained speed (Dogan and Pahre 1989). However, the boundary lines between the disciplines still remain. During this period, the interdisciplinary discoveries, such as George Mendel's discovery of the structure of DNA, could easily go unnoticed, as actually happened, since his work involved more than one field of study (he included in his paper math calculations that were not common in the field of biology). It was suggested that the mathematical description of the hereditary process in Mendel's work was the reason why Charles Darwin did not relate his work to that of Mendel, although it was assumed that he was aware of Mendel's work on heredity (Galton 2009; Sclater 2006). Mendel's work was rediscovered 50 years later (Lewens 2015).

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It is assumed, therefore, that in the time of Leonardo da Vinci (1452–1519) a discovery or innovation that involved more than one field of science could become a sleeping beauty, that is, be premature, and its recognition delayed; it could take a decade, and sometimes several decades, and more rarely a whole century, before it is awakened.

Another characteristic of late Medieval and Renaissance times that could contribute to the late recognition of scientific discoveries was that in Leonardo's lifetime there was a complete separation between craftsmanship and university science. The university scholars at that time were working on theories and experimented without using a laboratory or observing nature directly, as da Vinci did (Fiorentino 2015, p. 229). That is, theory and practice remained separate without creating constructive knowledge. In his experiments and observations, he combined the arts and the sciences, and his deductions were acquired through observations and actual experimentation, several of which were described later in his paintings (Livio 2017, p. 27). Amid this reality, da Vinci remained a unique phenomenon, a man who observed sciences in an artistic way and art in a scientific way.

In our study we aim to present aspects of delayed recognition of da Vinci's science: his innovations in the 15th and 16th centuries and contributions to science, in various disciplines that started being observed in publications during the 20th and 21st centuries in growing numbers. The difference between the late recognition of da Vinci and other forgotten innovative discoveries is that other delayed recognitions involved a breakthrough book (Tal and Gordon 2017), or an article with a new idea (van Raan 2004), whereas da Vinci's innovations were related to many innovative aspects of many sciences.

The citation pattern of a delayed recognition suggested by van Raan cannot be applied to the case of da Vinci, because of the long sleep of his contributions to science. Nevertheless, the length of time of da Vinci's case is not unique in this respect; a paper by Julius Comroe (1976) lists 132 cases in medicine with a 350-year delayed recognition. The uniqueness of da Vinci is the multitude and interdisciplinary nature of his discoveries.

The Literature on Sleeping Beauty in the Sciences

Recognition in science is a very complicated phenomenon, its dynamics can vary from an instantly cited publication to a totally forgotten one. Some still wait for rediscovery. A paper whose importance went unnoticed for a long time and suddenly attracts a lot of attention has been called a Sleeping Beauty (SB) (van Raan 2004). According to van Raan (2004), there are three main variables to measure the sleep of such papers: (1) depth of sleep (deep sleep (one citation per year) and less deep sleep (one to two citations on average per year during a specific period)); (2) length of the sleep (duration of the above period); and (3) awake intensity (number of citations per year, during the four years following the sleep period). What are the origins of the phenomenon of Sleeping Beauties in science? In some situations, it seems inevitable: the paper being lost through the ages, or lying in a place difficult to discover, or simply being a victim of information overload nowadays; all this makes rediscovery a difficult process. Even without all the reasons mentioned above there are other obstacles: author's poor communication skills (Price 1976; Tal and Gordon 2017); findings that do not agree with current accepted theory (Cole 1970), author's low position in the hierarchy of science (the Matthew Effect) (Cole 1970; Merton 1968; Tal and Gordon 2017); content that cannot be extended experimentally to prevailing knowledge for technical reasons (Tal and Gordon 2017; Wyatt 1961); question of legitimacy of the application of methods from one scientific domain to another (Mendel's Effect) (Garfield 1980), the peer review system (Campanario 1996; Tal and Gordon 2017); paper's relevance to another discipline (failed interdisciplinary communication) (Ke et al. 2015); lack of awareness of scientific development in undeveloped countries in the developed world and vice versa (Sharma and Sen 2006; language barriers between English and non-English speaking scientists (Schubert and Glanzel 2006); wrong choice of type of journal/publisher where the work is published (Bornmann and Daniel 2010),and low ranking of the journal/publisher (the Matthew Effect) (Huggett 2013; Merton 1968). According to Ke and his colleagues (Ke et al. 2015), interdisciplinary works have the highest chance of becoming Sleeping Beauties.

Research Questions

Does the citation trend to works on Leonardo da Vinci show a delayed recognition pattern? And if so, what publication has "awakened" it?

Methodology

The source of data in this study is Google Scholar, which indexes old material that cannot be found in bibliographic databases such as Scopus and the World of Science. The Publish or Perish (PoP) database that relies on Google Scholar data, among other databases, was used for categorial data that enumerates da Vinci's contributions in various areas of science. In addition, the data coverage on da Vinci on PoP in relation to several disciplines was compared with the same coverage of the bibliographic database Scopus to determine the effect of selectivity and time on the material retrieved.

The search term by topic was "Leonardo da Vinci"; that is, it includes every paper that mentioned da Vinci as a main

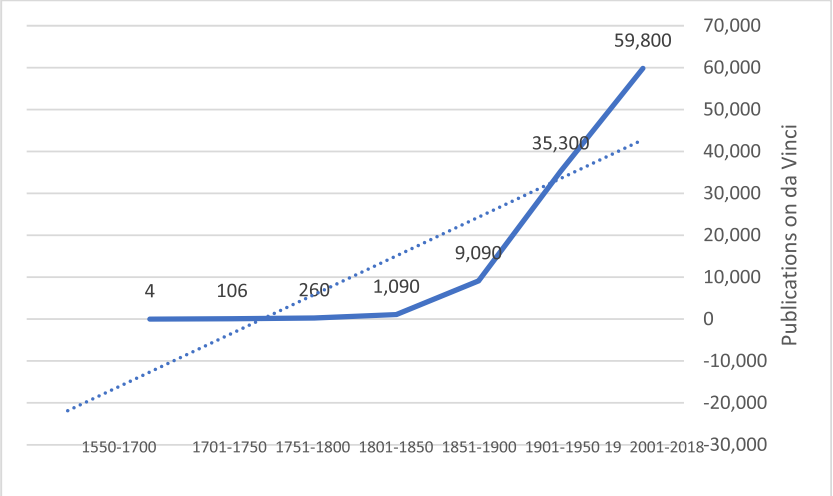

Fig. 1 Publication trend on da Vinci (Source: Google Scholar)

figure or as an example or from other aspects. The term "publication" in this study refers to any type of publication, a scientific paper, books, white papers, articles from blogs, etc.

In tracing the awakening of da Vinci's recognition, we realized that the criteria for sleeping beauties suggested by Jiang and Dongbo (2016) can be applied to da Vinci's case. These authors concluded that the lower the slope on the exponential function the longer the SB's sleep. Nevertheless, demonstrating this trend in da Vinci's case needs the enumeration of time by centuries rather than by years. Therefore, a more suitable criterion to da Vinci's case was devised, pinpointing the awakening time of da Vinci's work to a paper on da Vinci that created a continuous large body of citations over time.

Results and Discussion

The data on Google Scholar (Fig. 1) shows an increase in the number of publications on da Vinci in the eighteenth century, but a real "jump" in the writings about him in the nineteenth century. In the 20th and 21st centuries the growth of the literature on da Vinci is even more manifest, but this could be attributed partly to the general growth of the number of publications in these two last centuries that are marked by fast technological innovations that influenced the general growth of the published literature over time.

Figure 2 shows that the citations to the study that awakened the literature on da Vinci started about 400 years following the first publications on the person and his work and increased gradually until the twentieth century. The most notable increase in the general number of citations to studies on his work started in the mid-twentieth century and continues this growth rate in the twenty-first century.

Even though the early studies on da Vinci 1650 to 1700 were cited further, they did not accumulate a large body of continued citations, so these papers could not be considered an awakening of a sleeping beauty according to our definition. Therefore, we decided to look for the first paper on da Vinci that has several citation levels and evolved into a body of cited literature.

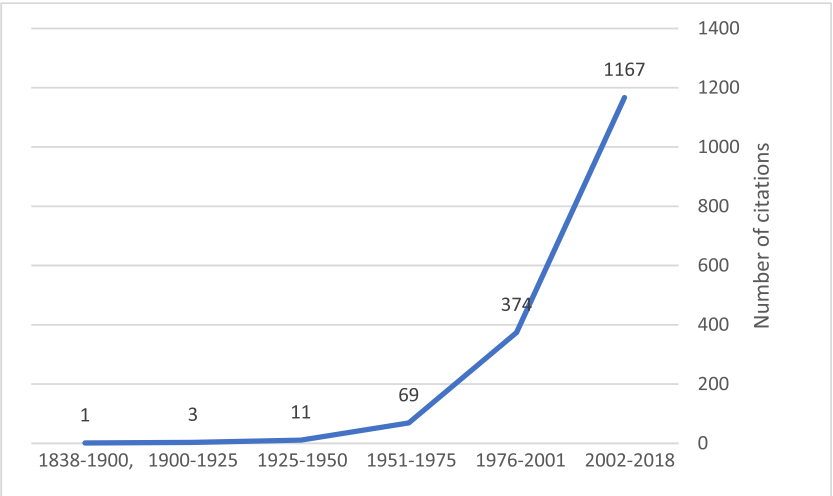

Fig. 2 Citations trend to the earliest paper citing da Vinci's work (Source: GS)

Table 1 Publications and Citations to papers mentioning Leonardo da Vinci (Publish or Perish, 2018)

Areas of study	Years	Publications	Citations	Cites per paper
Medicine	1883–2018	980	94,383	96.3
Technology	1894–2018	480	59,975	124.9
Art	1810–2018	992	133,378	134.4
Physics	1800–2018	980	77,960	79.5
Chemistry	1856–2018	987	66,094	66.9
Materials	1882–2018	975	123,138	126.3

It was found, in a Google Scholar search, that the earliest paper mentioning da Vinci's work and accumulating a very large number of citations was written in 1838 and entitled "Contributions to the Physiology of Vision. –Part the First. On Some Remarkable, and Hitherto Unobserved, Phenomena of Binocular Vision" written by Charles Wheatstone and published in the journal *Philosophical Transactions of the Royal Society of London*, Vol. 128 (1838), 371–394. This author investigated human vision from long and short distances, and referring to his own observations he wrote that nobody before him, except for da Vinci, in his oeuvre *Trattato della Pittura*, observed that the exact vision of light and contour of a painting can be seen in exactitude only from a distance.

The value of da Vinci's contribution to science, therefore, was first observed and cited in this paper that deals with human vision. This paper produced 1626 further citations from 1838 to 2018. That is, the awakening time to da Vinci's contributions to science occurred almost 400 years after his death, and the awakening paper was in the area of human physiology. The fact that da Vinci's first recognized contribution is in the area of vision is not surprising. Giovio (1970), who wrote on da Vinci's work, noted that da Vinci was most interested, among others medical subjects, in the area of optics. According to the PoP database, since 1883 to these days 980 papers and books in medicine referring to da Vinci's work were written and cited 94,383 times. This led us to further investigation of publications and citations mentioning da Vinci's work on Google Scholar, in several disciplines.

The number of publications mentioning da Vinci in some form on Google Scholar is 197,000 (as retrieved on June 23, 2018). This "big data" mentioning da Vinci in relation to the sciences and the art is divided as shown in Table 1.

The numbers shown in Table 1 are not a fixed division among disciplines, and there are vast areas of publications' interdisciplinarity. The crossroad between disciplines, which also characterizes da Vinci's work, is the source of ingenuity and as Nissani puts it: "Many complex or practical problems can only be understood by pulling together insights and methodologies from a variety of disciplines." (Nissani 1997, p. 209). This trend is evident in da Vinci's work and in the publications and citations mentioning his heritage.

The cite per paper of the various disciplines measured on PoP shows the large number of citations to the publications in these areas. That is, the citations for these areas of study follow the usual trend, except for the large number of citations in art that could be understood in relation to da Vinci's work, but otherwise this discipline is part of the humanities that regularly are not cited so extensively.

The comparison of the coverage of several disciplines in PoP, which is based on Google Scholar data, and Scopus, which is a subscription bibliographic database, shows the different emphasis and weight given to each discipline by these search tools. While Scopus relates publications in physics as most prominent in relation to da Vinci, the open Google Scholar data analyzed by PoP relates to him mostly in publications in the arts. Also, despite the fact that PoP limits the retrieval set to 1000 publications, the number of citations to this limited set is much higher than it is on Scopus. This result could be attributed to the difference in the coverage time range of the search tools, as well as to the database limitations. In addition, it is important to note that publications cited in Table 2 include not only Leonardo da Vinci as a main theme but also articles that mention his scientific contributions in a certain context.

Table 2 Publications and citations to papers on Leonardo da Vinci-Scopus and PoP compared

Scopus 1960–2018				Publish or Perish 1747–2018		
Science areas	Publications $N = 9087$	Citations $N = 137,718$	Field weighted citations	Publications $N = 980$*	Citations $N = 554,928$	Field weighted citations
Medicine	1366	16,111	11.70	980	94,383	17.00
Physics	1266	26,952	19.57	980	77,960	14.04
Chemistry	645	12,295	8.92	987	66,094	11.91
Art	1772	9222	6.69	992	133,378	24.03
Material	859	12,449	9.03	975	123,138	22.19
Technology	1243	22,100	16.04	480	59,975	10.80

*The PoP database limits the search results to 1000 publications

Conclusion

Leonardo da Vinci, an interdisciplinary researcher, became a "sleeping beauty" in science for more than 300 years, an unprecedented case in science history. His universal genius observed science in an artistic way and art in a scientific way, which makes him a rare phenomenon in his lifetime and even today. The bibliometric study we undertook has shown that even though the early studies on da Vinci 1650 to 1700 were cited further, they did not accumulate a large body of continued citations, so these papers could not be considered an awakening of a sleeping beauty according to our definition. The earliest paper mentioning da Vinci's work, followed by the large number of citations, was published in 1838 and was dedicated to optics, a topic in which Leonardo found a great interest and contributed a lot. Since then the number of citations of Leonardo's works increased continually. Our results show that academic interest in his contribution to physics leads the list of citations (based on the Scopus database) whereas popular interest (based on Google Scholar) lies in the sphere of art.

Limitations of this Study

PoP – designed for open access searching based on Google Scholar with no limitations on the type of material it includes (for example, blogs, posts, position papers, very old papers). In comparison to PoP, Scopus is a selective database that indexes only a certain type of material (for example, academic articles, books, conference papers). The use of a non-selective search engine as data source could be considered a limitation because of the varieties of type of material retrieved by it, which are not categorized, but specifically in this kind of study there was a need to go back to very early times to observe the writings on a 500-year genius, assuming that the awakening of the work of this figure should also be several decades ago, which made the use of Google Scholar as data source a necessity, since other databases, especially bibliographic ones, do not provide such early data.

Further Reading

Andersen, H. 2013. The second essential tension: On tradition and innovation in interdisciplinary research. *Topoi*, *32*, 3–8.

Bornmann, L., & Daniel, H. D. 2010. Citation speed as a measure to predict the attention an article receives: An investigation of the validity of editorial decisions at Angewandte Chemie. *Journal of Informetrics*, *4*(1), 83–88.

Bromham, L., Dinnage, R., & Hua, X. 2016. Interdisciplinary research has consistently lower funding success. *Nature*, *534*(7609), 684–687.

Campanario, J. M. 1996. Have referees rejected some of the most-cited articles of all times? *Journal of the American Society for Information Science*, *47*(4), 302–310.

Cole, S. 1970. Professional standing and the reception of Scientific discoveries. *American Journal of Sociology*, *76*(2), 286–306.

Comroe, J. H. 1976. How to succeed in failing without really trying. *American Review of Respiratory Diseases*, *114*, 629–634.

Dogan, M., & Pahre, R. 1989. Fragmentation and recombination of the social sciences. *Studies in Comparative International Development*, *24*(2), 56–73.

Fiorentino, F. 2015. Late medieval science and modern science: Two culture options? *Viator*, *46*(3), 219–234.

Galton, D. 2009. Did Darwin read Mendel? *Quarterly Journal of Medicine*, *102*, 587–589.

Garfield, E. 1980. Premature discovery or delayed recognition – Why? *Essays of an Information Scientist*, *4*, 488–493.

Giovio, P. 1970. Leonardo Vincii Vita. In J. P. Richter (Ed.), *The literary works of Leonardo da Vinci* (vol. 1, 3rd ed., pp. 1–544). London: Phaidon.

Haskins, C. H. 1957. *The rise of universities*. Ithaca:Ballow Press.

Huggett, S. 2013. Journal Bibliometrics indicators and citation ethics: A discussion of current issues. J. P. Richter (Ed.), *The Literary Works of Leonardo da Vinci*, 3rd ed. *Atherosclerosis, 230*(2), 275–277.

Jiang, L., & Dongbo, S. 2016. Sleeping beauties in genius work: When were they awakened? *Journal of the association for information science and technology*, *67*(2), 432–440.

Ke, Q., Ferrara, E., Radicchi, F., & Flammini, A. 2015. Defining and identifying sleeping beauties in science. *Proceedings of the National Academy of Sciences*, *112*(24), 7426–7431.

Kuhn, T. S. 1959. The essential tension: tradition and innovation in scientific research. In C. W. Taylor, & F. Barron (Eds.), *Scientific creativity: its recognition and development* (pp. 341–354). New York: Wiley, New York.

Lewens, T. 2015. The nature of philosophy and the philosophy of nature (book review). *Biology & Philosophy*, *30*(4), 587–596.

Livio, M. 2017. *Why? What makes us curious*. New York:Simon and Schuster.

Merton, R. K. 1968. The Matthew effect in science. *Science*, *159*(3810), 56–63.

Nissani, M. 1997. Ten cheers for Interdisciplinarity: The case for interdisciplinary knowledge and research. *The Social Science Journal*, *34*(2), 201–216.

Price, D. J. D. 1976. Telephone communication. A general theory of bibliometrics and other cumulative advantage processes. *Journal of the American Society for Information Science*, *27*, 292–306.

Schubert, A., & Glanzel, W. 2006. Cross-national preference in co-authorship, references and citations. *Scientometrics*, *69*(2), 409–428.

Sclater, A. 2006. The extent of Charles Darwin's knowledge of Mendel. *Journal of Biosciences*, *31*(2), 192–193.

Sharma, H. P., & Sen, S. K. 2006. Shubnikov: A case of non-recognition in superconductivity research. *Current Science*, *91*(11), 1576–1578.

Tal, D., & Gordon, A. 2017. Sleeping beauties of political science: The case of AF Bentley. *Society*, *54*(4), 355–361.

van Raan, A. F. J. 2004. Sleeping beauties in science. *Scientometrics*, *59*(3), 467–472.

Wheatstone, C. 1838. Contributions to the physiology of vision. –part the first. On some remarkable, and hitherto unobserved, phenomena of binocular vision. *Philosophical Transactions of the Royal Society of London*, *128*, 371–394 Retrieved from http://www.jstor.org/stable/108203.

Wyatt, H. V. 1961. Knowledge and prematurity – Journey from transformation to DNA. *Perspectives in Biology and Medicine*, *18*, 596–602.

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